

# Determining atmospheric aerosol content with an infra-red radiometer

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**Abstract.** The attenuation of atmospheric Cherenkov photons is dominated by two processes: Rayleigh scattering from the molecular component and Mie scattering from the aerosol component. Aerosols are expected to contribute up to  $30 \text{ Wm}^{-2}$  to the emission profile of the atmosphere, equivalent to a difference of  $\sim 20^\circ\text{C}$  to the clear sky brightness temperature under normal conditions. Here we investigate the aerosol contribution of the measured sky brightness temperature at the H.E.S.S. site; compare it to effective changes in the telescope trigger rates; and discuss how it can be used to provide an assessment of sky clarity that is unambiguously free of telescope systematics.

**Keywords:** lidar, infrared instrumentation, ground based gamma-ray astronomy

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## INTRODUCTION

The atmosphere is the most important part of the detector in ground-based gamma-ray astronomy, but it is also the part that has the greatest systematic uncertainty and over which we have the least control. It falls upon us to instead monitor and characterise the atmospheric conditions at the time of observations so that we can either feed this information into Monte Carlo simulations or reject data when conditions go out of acceptable parameters.

After being generated in the upper atmosphere Cherenkov light will either reach the ground or be attenuated through the process of Rayleigh scattering on the molecular component of the atmosphere, or Mie scattering on the aerosol component (variously dust, silicates, pollens, etc). The molecular component tends to change relatively slowly, through seasonal variations; whereas the aerosol component can change more rapidly, depending on eg wind conditions. It becomes vitally important to characterise this aerosol component of the atmosphere through regular monitoring. A lidar is generally used to measure the atmospheric transmission (eg [1]) from backscattered laser light. At the H.E.S.S. site a lidar centred at 355 and 532nm has been running in conjunction with observations since mid-2011. Whilst lidars are excellent instruments for determining the presence of aerosols they are not without complications. Firstly a lidar, due to geometric viewing considerations, only becomes effective above a minimum altitude. Secondly, in order to obtain a transmission profile relevant to the Cherenkov spectrum the laser wavelengths are close to the peak in the emission, this means the lidar is operated only inbetween observing runs to avoid any light contamination to the telescope images. In this paper we look at utilising another piece of the H.E.S.S. atmospheric monitoring equipment to fill in some of this missing information.

The atmosphere is split into regions according to its temperature behaviour. The troposphere is the lowest, most dense, part of the atmosphere – where most of the weather happens – and is characterised by a linear decline in temperature with increasing altitude and vertical mixing. The molecular density profile falls off exponentially, with a scale height of a few km; the vertical air motion in this region mixes in the larger aerosols which have a smaller scale height of order a km. The molecular component is an inefficient black-body radiator in the 8-14 $\mu$ m region of the spectrum, water vapour and aerosols are slightly more efficient and clouds are very efficient. This makes an infra-red radiometer an effective cloud monitor, with clouds showing up as a large brightness temperature compared to a relatively “cold” sky [2]. H.E.S.S. employ Heitronics KT19.82 radiometers with 2° field of view to monitor for the presence of clouds, with each telescope having a paraxially mounted unit and a further one continuously scanning the whole sky. The infra-red luminosity of the sky ( $L_{\text{sky}}$ ) is a collective sum of the emission of a number of different constituent parts

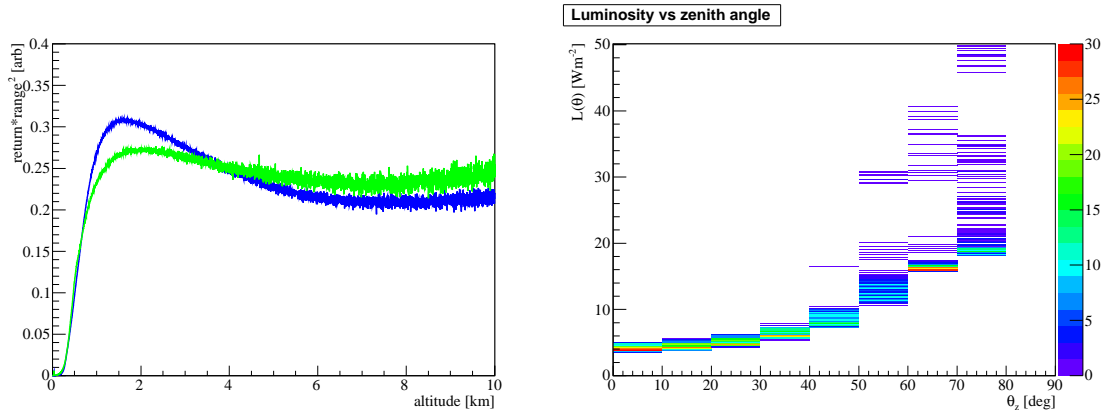
$$L_{\text{sky}} = \epsilon_l \sigma T_{\text{lens}}^4 + \epsilon_{wv} \sigma T_{wv}^4 + \epsilon_a \sigma T_a^4 + \epsilon_m \sigma T_m^4 + \dots \quad (1)$$

where  $\epsilon$  is the emissivity of the lens ( $l$ ) and the water vapour  $wv$ , the aerosols  $a$ , and the molecular ( $m$ ) profiles of the atmosphere, etc and  $T$  is the relevant integrated temperature profile in the line of sight. According to [3] the aerosol component can contribute up to 30Wm<sup>-2</sup> to the bolometric luminosity, which can mean the difference between a brightness temperature of -56°C or -70°C in the presence or absence of aerosols respectively. This leads to the prospect of changing aerosol conditions leading to a noticeable change in the sky brightness temperature ( $T_{\text{sky}}$ ) measurements.

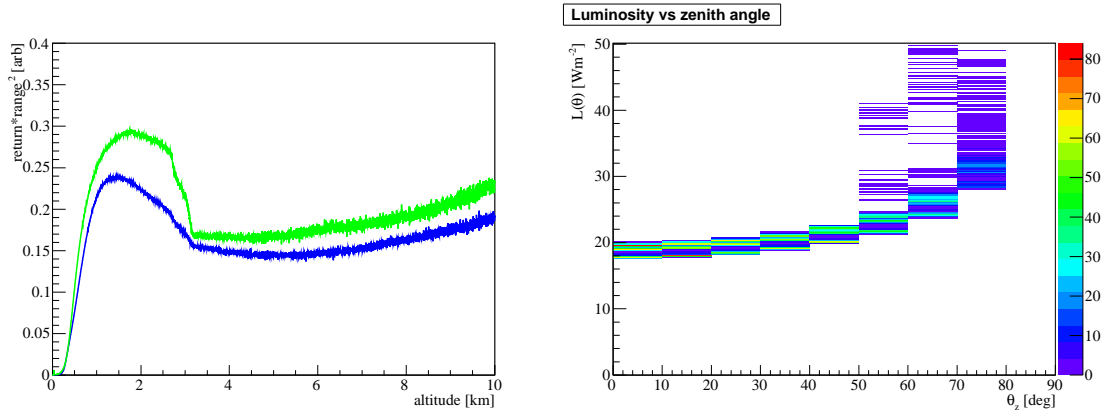
## DATA AND OBSERVATIONS

The August to September period at the H.E.S.S. site often has noticeable aerosol contamination due to biomass burning in neighbouring countries and the resultant smoke being blown downwind. In figure 1 we see an “ideal” night which has no measurable aerosol contribution (the large particles having sedimented out of the atmosphere); within the space of a week figure 2 shows “hazy” conditions, with a prominent aerosol boundary layer that extends up to about  $\sim 3$ km; a couple of days later figure 3 shows the aerosols sedimenting out once more, with the boundary layer close to the lidar effective altitude threshold at  $\sim 1$  km (characteristic of “normal” observing conditions).

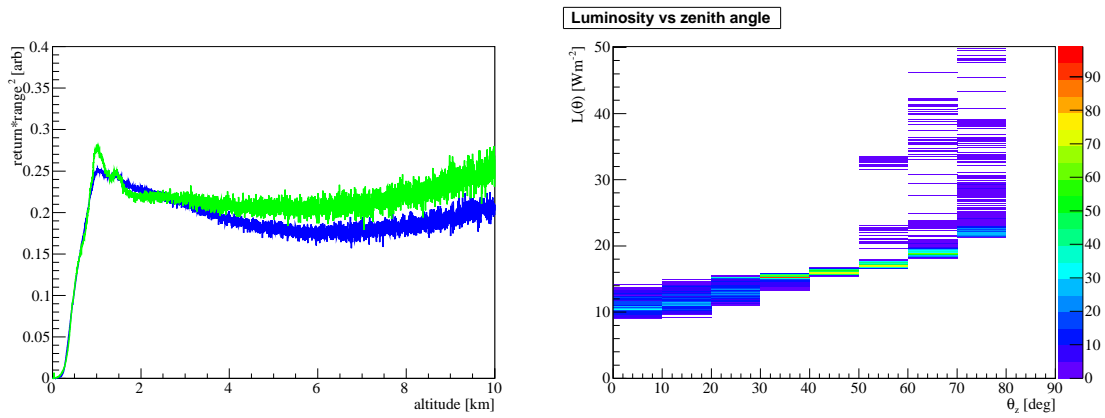
In figure 4 we show the telescope trigger rates as a function of zenith angle for all observing runs for that observing period that have 4 telescopes participating, stable rates (ie no clouds or data acquisition issues) and noted as clear by the observers in the shift logs. The data points are sub-divided according to the aerosol boundary layer conditions and the  $T_{\text{sky}}$  at zenith for that run, the correlation between warm sky temperature, aerosol presence and lowered telescope trigger rate is clearly apparent.



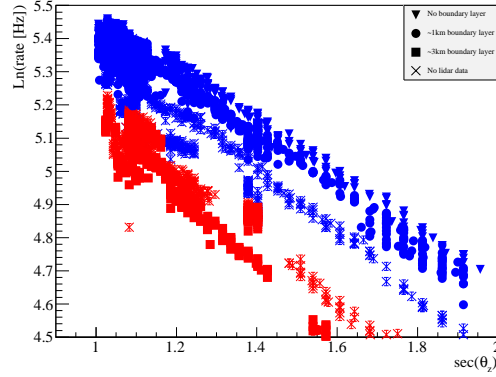
**FIGURE 1.** Sky conditions on the night of 20/08/2011. The left hand plot is the lidar profile (blue at 355nm, green at 532nm), showing no observable aerosol boundary layer; the right plot gives the histogram of infra-red luminosity measurements as a function of zenith angle.



**FIGURE 2.** As figure 1 but for the night of 29/08/2011. There is a prominent aerosol component up to a boundary layer of  $\sim 3$ km and the infra-red luminosity is substantially increased.



**FIGURE 3.** As figure 1 but for the night of 01/09/2011. There is a noticeable aerosol component up to a boundary layer of  $\sim 1$ km and the infra-red luminosity is moderately increased.



**FIGURE 4.** Telescope trigger rates as a function of zenith angle. The triangles correspond to periods with no observed boundary layer, circles when the boundary layer is at  $\leq 1$  km, squares when the boundary layer reaches  $\sim 3$  km and crosses for when there are no measurements available. The red points are when  $T_{\text{sky}}$  at zenith is  $\geq -50^\circ\text{C}$ , blue points when it is lower.

## DISCUSSION & CONCLUSIONS

The atmospheric clarity conditions according to lidar and infra-red radiometer measurements have been presented here. The presence of aerosols in the atmosphere show up clearly in the lidar returns and also as a clear increase in  $T_{\text{sky}}$ . The data selected here come from a single two week period to ensure no seasonal temperature effects can bias the dataset. The  $T_{\text{sky}}$  will still change somewhat due to the day-to-day ambient temperature variation, however this would be expected to produce no more than a  $\sim 20\%$  difference – not the observed  $\sim 200\%$ . During the most severe periods of aerosol contamination the boundary layer can be seen to extend to relatively high altitudes. As the production height for air shower photons is above these aerosol layers they should act like filters only, but since the light of muon ring images (commonly used to determine the atmosphere’s contribution to the systematic uncertainty) develop within these layers they will have a distinctly different and more complicated response to different boundary layer altitudes. This will be something to examine in future work.

In summary, the lidar is extremely useful in determining the presence of aerosol layers and measuring the transmission profiles, but has limited resolution at altitudes  $\leq 1$  km and limitations as to when it can be operated; the infra-red radiometer is sensitive to the presence or absence of aerosols, operates all of the time and will be most sensitive to low altitude aerosols. Together they have the potential to quantify atmospheric opacity entirely independently of the telescope systematics.

## REFERENCES

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